DUAL MODE PLANAR FILTER BASED ON SMOOTHED CONTOUR RESONATORS

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The present invention generally relates to the field of communication systems. More particularly, the present invention relates to a dual mode planar filter for use in high-frequency signal processing devices used in communication systems.

High frequency resonating filters are essential in the field of high-frequency communication systems. In particular, the field of mobile communication systems requires filters able to efficiently use the frequency band. Further, in base stations for mobile communications, filters having little loss, compact size and durability against a large electric power are desirable.

A wide variety of high-frequency resonating filters are known in the art.

For instance, in US 5,136,268 a dual mode microstrip resonator usable in the design of microwave communication filters is disclosed. The substantially square resonator provides paths for a pair of orthogonal signals, which are coupled together using a perturbation located in at least one corner of the resonator. The perturbation can be introduced by notching the resonator or by adding a metallic or dielectric stub to the resonator.

The Applicant has observed that the filter above described can have problems due to the fact that electric current tends to concentrate at the corners of the resonator to considerably increase resistance loss therein. This can lead to a degradation of the Q-value of the resonator and therefore and increased loss in the filter.

In US 5,172,084 planar dual mode filters are formed

by a conductive resonator having circular symmetry and two pairs of symmetrically oriented planar conductive leads. The conductive leads are aligned colinearly with two orthogonal diameters of the circular conductive resonator. A perturbation located on a region axis oriented symmetrically with respect to the two pairs of conductive leads couples electromagnetic modes which are injected into the resonator by the planar conductive leads. Higher order filter circuits can be realized by combining multiple filters. The filters are amenable to printed circuit (microstrip to stripline) fabrication using superconductors for the conductive elements.

However, the Applicant has observed that also these type of filters can have problems due to the fact that an excessive concentration of electric current can occur at the edges of the perturbation, leading to a degradation of the Q-value of the resonator and increased loss in the filter.

In US 6,239,674 a resonator having high Q-value is disclosed. The resonator has a compact structure with little loss caused by the conductor's resistance. The conductor of elliptical shape forming the resonator has two points along its circumference at which both of the two orthogonal resonating modes of the resonator are excited equally.

The Applicant has observed that in these types of filters it is rather complicated obtaining the coupling between the two resonating modes. In fact, as disclosed above, this coupling is obtained only bonding the input/output terminals of the filter at appropriate points along the conductor circumference.

The Applicant faced the problem of realizing a planar filter in which the coupling between the resonating modes can be easily obtained maintaining high

Q-values and low loss.

In particular, the Applicant has found that this problem can be solved by realizing a planar filter comprising a planar resonator including a conductive region having smoothed contours and supporting a first resonating mode propagating along a first conductive path and a second resonating mode propagating along a second conductive path, perpendicular to the first conductive path. The planar filter also comprises a conductor-free region made in the conductive region and having smoothed contours. The conductor-free region is disposed along a region axis forming an angle θ with respect to the first conductive path. The conductor-free region causes a perturbation of the symmetry of the planar resonator resulting in a frequency shift of the first and the second resonating mode and their mutual coupling.

According to an aspect of the present invention, there is provided a planar filter comprising:

- a planar resonator including a conductive region supporting a first resonating mode propagating along a first conductive path, said conductive region being a smoothed contour shaped region; and

- a conductor-free region made in said conductive region;

wherein said conductor-free region is a smoothed contour shaped region symmetrically disposed along a region axis forming an angle θ with respect to said first conductive path.

According to a further aspect of the present invention, there is provided a receiver front-end for use in a transceiver station of a wireless communication network, said receiver front-end comprising:

- a first node coupled to a transceiver antenna;

- a second node coupled to signal processing sections of said transceiver station; and

- a receiving branch inserted between said first and second nodes, said receiving branch comprising a cryostat enclosing a low noise amplifier;

wherein said cryostat encloses a planar filter made according to the present invention, said planar filter being mutually connected in cascade arrangement to said low noise amplifier.

Further preferred aspects of the present invention are described in the dependent claims and in the following description.

The features and advantages of the present invention will be made apparent by the following detailed description of some embodiments thereof, provided merely by way of non-limitative examples, which will be made referring to the attached drawings, wherein:

- figure 1 is a top view of a first embodiment of a dual mode planar resonator according to the present invention;

- figure 2 is a top view of a single mode planar resonator made according to the present invention;

- figure 3 is a top view of the dual mode planar resonator of figure 1 made with an inductive coupling;

- figure 4 is a top view of a second embodiment of the dual mode planar resonator of figure 1;

- figure 5 is a prospective view of a four pole planar filter according to the present invention;

- figure 6 is a prospective view of another four pole planar filter according to the present invention;

- figure 7 is a graph showing a reflection characteristic of the single mode planar resonator of figure 2;

- figure 8 is a graph showing a reflection

characteristic of the dual mode planar resonator of figure 1;

- figure 9 is a graph showing the frequency response of the four pole planar filter of figure 6; and

- figure 10 is a schematic representation of a receiver front-end using the dual mode planar filter of the present invention.

Figure 1 shows a dual mode planar resonator 1 comprised in a dual mode planar filter and including a conductive region 2 having smoothed contours and supporting two orthogonal resonating modes at desired frequencies.

In a first embodiment of the present invention, the conductive region 2 has a polygonal shape with edges significantly rounded. Preferably, the polygonal shape is a square shape or a rectangular shape.

In the remainder of the present description and claims we shall define as "edge significantly rounded" an edge having for example a bending radius in the range of about 10% ÷ 30% of the mean value of the polygon side lengths.

In an embodiment of the present invention shown in figure 1, the conductive region 2 has a substantially rectangular shape with side lengths l_1, l_2. In the conductive region 2 resonance of a first resonating mode occurs when side length l_1 is about half wavelength at the operating frequency. Similarly, resonance of a second resonating mode, orthogonal to the first resonating mode, occurs when side length l_2 is about half wavelength at the operating frequency.

Always with reference to figure 1, a first vector 3 is indicative of a first conductive path along which the first resonating mode propagates. Similarly, a second vector 4, perpendicular to the first vector 3, is

indicative of a second conductive path along which the second resonating mode propagates.

The dual mode planar resonator 1 also comprises a conductor-free region 5 made in the conductive region 2 and having smoothed contours. Specifically the conductor-free region 5 is symmetrically disposed along a region axis 6 forming an angle θ with respect to the orientation of vector 3.

Preferably, the conductor-free region 5 is an elliptical shape region having its major axis parallel to the region axis 6.

The conductor-free region 5 causes a perturbation of the symmetry of the dual mode planar resonator 1 resulting in a frequency shift of both orthogonal resonating modes represented by vectors 3, 4 and their mutual coupling.

Specifically, the tuning of the two orthogonal resonating modes and the control of their coupling can be easily achieved by varying the angle θ.

In particular, at $\theta = 0° \pm \cdot \pi/2$ no coupling is observed between the two orthogonal resonating modes. In this condition, the tuning of each resonating mode can be obtained independently, by varying the conductor-free region diameters ratio Dmax/Dmin. In both cases the planar resonator 1 operates as a single mode planar resonator. As shown in figure 2, in this case the conductor-free region 5 can be a circular shaped region.

When $\theta = 45° \pm \pi/2$ the conductor-free region 5 provides the maximum level of coupling between the two orthogonal resonating modes but, if the conductive region 2 is symmetric ($l_1 = l_2$), for symmetric reasons the same level of detuning take place for both the modes. In this

case the planar resonator 1 operates as a dual mode planar resonator with the maximum level of coupling.

However, tuning selectively the two orthogonal resonating modes is possible by varying the aspect ratio of the conductive region 2. In particular, the resonating mode represented by vector 3 can be tuned by varying the side length l_1 of the conductive region 2, while the resonating mode represented by vector 4 can be tuned by varying the side length l_2 of the conductive region 2.

Further, keeping the angular position θ fixed at $45° \pm \pi/2$ the coupling between the two orthogonal resonating modes can be finely adjusted by varying the conductor-free region diameters ratio Dmax/Dmin. The limit case of Dmax/Dmin = 1 corresponds to the case of no coupling already discussed.

Therefore, according to the present invention, when $\theta = 45° \pm \pi/2$ a fine tuning of the two resonating modes and a fine adjustment of the degree of their coupling can be achieved independently and in an easy manner.

Again with reference to figure 1, the dual mode planar resonator 1 further comprises at least a pair of planar conductive leads 7, 8 capacitively coupled to the dual mode planar resonator 1 through gaps C1-C2 respectively. Capacitive coupling coefficients between the planar conductive leads 7, 8 and the dual mode planar resonator 1 can be adjusted by varying the size and shape of gaps C1-C2 or the shape of the termination of conductive leads 7, 8. Alternatively, capacitive coupling can be achieved by using optional capacitive parts (such as a capacitor) to connect the planar conductive leads 7, 8 to the dual mode planar resonator 1.

Referring now to figure 3, in a different aspect of the present invention, the planar conductive leads 7, 8

can be inductively coupled to the dual mode planar resonator 1 through taps T1-T2 respectively. Alternatively, inductive coupling can be achieved by using optional inductive parts (such as a coil or a wire bond) or by using a fine lead line of a proper length to connect directly the planar conductive leads 7, 8 to the dual mode planar resonator 1.

Planar conductive lead 7 can act as input terminal of the dual mode planar resonator 1 while planar conductive lead 8 can act as output terminal. In this condition, high frequency signals are coupled into the dual mode planar resonator 1 from planar conductive lead 7 through gap C1 or tap T1. Similarly, high frequency signals are coupled out of the dual mode planar resonator 1 to the planar conductive lead 8 through gap C2 or tap T2. Alternatively, planar conductive lead 8 can act as input terminal of the dual mode planar resonator 1 while planar conductive lead 7 can act as output terminal.

With reference to figures 1, 2 and 3 in operation, a high frequency signal entering dual mode planar resonator 1 through planar conductive lead 7 and gap C1, or tap T1, introduces a first mode resonating along vector 3.

Conductor-free region 5 causes a perturbation of the current flow resulting in a coupling to the mode resonating along vector 4. Planar conductive lead 8 is used to extract the coupled high frequency signal from the dual mode planar resonator 1.

As shown in figure 4, a dual mode planar resonator 20 according to the present invention comprises a conductive region 21 having preferably an elliptical shape; the major and minor diameters of said elliptical conductive region being dimensioned to support two orthogonal resonating modes at a desired frequency.

The other parts of the dual mode planar resonator 20

are the same as those described with reference to the dual mode planar resonator 1 of figures 1, 2 and 3 and therefore they will not be described again.

As shown in figure 4, in this case, a high degree of input/output coupling can be achieved by widening the end of the conductive leads 7, 8 and/or by varying the angular position θ_1 of the planar conductive lead 8 with respect to the orientation of the vector 3. In fact, if the planar conductive lead 8 is positioned at an angle θ_1 with respect to the orientation of the vector 3, the coupled high frequency signal extracted from the dual mode planar resonator 20 is a linear combination of the two orthogonal resonating modes 3, 4. This degree of freedom is useful for obtaining more complex filter transfer functions.

Advantageously, in both the embodiments of the present invention, the conductive region 2, 21 can be made by a high-temperature oxide superconductor represented by: an yttrium (Y) family superconductor such as $YBa_2Cu_3O_x$ or the like; a bismuth (Bi) family superconductor such as $Bi_2Sr_2Ca_2Cu_3O_x$ or the like; a thallium (TI) family superconductor such as $TI_2Ba_2CaCu_2O_x$ or the like; a metallic superconductor such as Nb or the like. Less preferably, by an ordinary conductor such as gold, copper, etc.

It should be noted that in general, using a superconductor as the conductor material of a resonator provides a considerable decrease in conductor loss which increases the resonator's Q-value drastically. However, a current density exceeding the value of the superconductor material's critical current density cannot be applied. This becomes a problem in the case of handling high frequency signals having high power. As mentioned before, since the dual mode planar resonator 1 of the present invention has a structure preventing peak current density,

by using a superconductor material for the conductive region 2, 21, a high frequency signal of a larger power can be used as compared with dual mode resonating filters having conventional structures. Consequently, a dual mode planar resonator having a high power handling capability is obtained.

In figure 5 there is illustrated a prospective view of a four pole planar filter 30 based on microstrip technology and utilizing two dual mode planar resonators made according to the present invention. Alternatively, the four pole planar filter 30 can be based on a stripline technology.

Specifically, the four pole planar filter 30 is formed by depositing first and second conducting layers 31, 32 on opposed faces of a dielectric slab 33. The dielectric slab 33 can be made by alumina or sapphire having a dielectric constant ϵ_r of about 10. The dielectric slab 33 can also be made by quartz having a dielectric constant ϵ_r of about 3.78.

Preferably, the first conductive layer 31 is made by a high-temperature oxide superconductor of the type described above with reference to the conductive region 2, 21. In this case, the dielectric slab 33 can be preferably made by dielectric materials such as Lanthanum Aluminate ($LaAlO_3$) having a dielectric constant ϵ_r of about 24, Magnesium Oxide (MgO) having a dielectric constant ϵ_r of about 10, etc.

First and second dual mode planar resonators 34, 35 and planar conductive leads 36, 37, 38 are generated on the top of the dielectric slab 33 by etching the first conductive layer 31. The second conductive layer 32 on the bottom of the dielectric slab 33 serves as a ground plane.

Planar conductive leads 36, 37, 38 are capacitively coupled to the dual mode planar resonators 34, 35.

Specifically, at a frequency of about 2 GHz, with a dielectric slab having a dielectric constant of about 24 and a thickness of about 0,5 mm, each planar resonator 34, 35 can have side lengths l_1, l_2 in the range of about 10 ÷ 15 mm.

In operation, the planar conductive lead 36 provides energy from a high frequency signal to the first dual mode planar resonator 34 where a respective conductive-free region 39 couples some of this energy into an orthogonal mode. Energy is coupled out of the first dual mode planar resonator 34 and into the second dual mode planar resonator 35 by means of the planar conductive lead 37. Additional second order filtering is introduced in the second dual mode planar resonator 35. The output high frequency signal of this four pole planar filter 30 is extracted through the planar conductive lead 38.

In figure 6 there is illustrated a prospective view of a four pole planar filter 40 according to the present invention. The four pole planar filter 40 comprises planar conductive leads 41, 42 inductively coupled to respectively first and second dual mode planar resonators 43, 44 made according to the present invention. The four pole planar filter 40 also comprises a planar conductive lead 45 capacitively coupled to both the first and the second dual mode planar resonator 43, 44.

The other parts of the four pole planar filter are the same as those described with reference to figure 5 and therefore they will not be described again.

In operation, the planar conductive lead 41 couples inductively input energy to the first dual mode planar resonator 43 where a respective conductive-free region 39 couples some of this energy into an orthogonal mode. This orthogonal mode is capacitively coupled out of the first

dual mode planar resonator 43 and into the second dual mode planar resonator 44 by means of the planar conductive lead 45. Additional second order filtering is introduced in the second dual mode planar resonator 44. The output high frequency signal of this four pole planar filter 40 is inductively extracted through the planar conductive lead 42.

Advantageously, a refinement tuning of the coupling between the two dual mode planar resonators 43, 44 can be obtained by varying the length of the planar conductive lead 45.

With reference to figures 7 and 8, the Applicant has simulated (using "Sonnet" commercial software) the dual mode planar resonator 1 according to the first embodiment of the present invention.

Specifically, figure 7 shows the reflection characteristic with respect to the frequency of the dual mode planar resonator 1 operating in single-mode. The reflection characteristic was measured at the planar conductive lead 7 using a capacitive coupling between the planar conductive lead 7 and the planar resonator 1. The conductor-free region 5 was an elliptical shape region centred at the intersection of the two vectors 3, 4 and having its major axis parallel to the vector 3 ($\theta = 0°$ or $\theta = 90°$). As disclosed above, in this case no coupling is observed between the two orthogonal resonating modes. According to this the reflection characteristic has only one resonance peak that, in this case, is at a frequency of $\approx$ 1,98 GHz with a magnitude of $\approx$ -4.8 dB.

Figure 8 shows the reflection characteristic with respect to the frequency of the dual mode planar resonator 1 operating in dual mode. The reflection characteristic was measured at the planar conductive lead

7 using a capacitive coupling between the planar conductive lead 7 and the planar resonator 1. The conductor-free region 5 was an elliptical shape region centred at the intersection of the two vectors 3, 4 and having its major axis forming an angle $\theta = 45°$ with respect to the vector 3. As disclosed above, in this case the maximum level of coupling between the two orthogonal resonating modes is observed. According to this the reflection characteristic has two resonance peaks that in this case are at a frequency $f_1 \approx 1.922$ GHz with a magnitude of ≈ -0.0455 dB and at a frequency $f_2 \approx 1.998$ with a magnitude of ≈ -0.035 dB. The coupling coefficient k between the two resonating modes is represented by the following expression:

$$k = \frac{\Delta f}{f_0}$$

where Δf is the distance between the two resonance peaks and f_0 is their mean value. For the dual mode planar resonator having the reflection characteristic of figure 8 the coupling coefficient k is equal to 0.0389.

Further, it should be noted from figures 7 and 8 that the dual mode planar resonator of the present invention has a relatively high Q-value.

In addition the dual mode planar resonator according to the present invention has small size and low mass.

Referring now to figure 9, the Applicant has simulated (using "Sonnet" commercial software) the operation of the four pole planar filter 40 shown in figure 6.

In particular, figure 9 shows the transmission curve T and the reflection curve R of the four pole planar

filter 40 measured when both the elliptical shape regions of the dual mode planar resonators 43, 44 have an angular position $\theta = 45°$ providing the maximum level of coupling between the two orthogonal resonating modes.

As shown in figure 9, the four pole planar filter 40 has a bandwidth Δf of about 76 MHz centred at $f_o \cong 1,950$ GHz.

Specifically, the transmission curve T has two zeros at 1,810 GHz and 2,118 GHz due to an extra coupling between a mode resonating in the dual mode planar resonator 43 along a direction parallel to conductive lead 41 and a mode resonating in the dual mode planar resonator 44 along a direction orthogonal to conductive lead 42.

The simulated in-band return loss is better than 24 dB.

Small size and low mass make the dual mode planar filter of the present invention suitable for example for use in transceiver station receiver front-ends.

According to this, figure 10 illustrates a schematic representation of a receiver front-end 100 for use in a transceiver station of a wireless communication network. The receiver front-end 100 comprises a dual mode planar filter, made according to the present invention.

In detail, the receiver front-end 100 comprises a first node 101 adapted for coupling a transceiver antenna 102 and a second node 103 adapted for coupling to signal processing sections 104 of the transceiver station. Between the first and the second node 101, 103 there are inserted a transmitting branch 105 and a receiving branch 106. The transmitting branch 105 comprises a transmitting filter 107 while the receiving branch 106 comprises a cryostat 109 enclosing a dual mode planar filter 110, made according to the present invention, and a low noise

amplifier (LNA) 111, mutually connected in cascade arrangement.

Preferably, the transmitting filter 107 can also be made according to the present invention.

In operation, the radio signal received by the transceiver antenna 102 is sent to the first node 101. In the first node 101 the radio signal is addressed to the receiving branch 106. In the cryostat 109 the radio signal is filtered by the dual mode planar filter 110 and then amplified by the low-noise amplifier 111. The resulting radio signal is then sent to the signal processing sections 104.

The transmitting branch 105 is used for the RF communication between the transceiver station and a plurality of communication devices located in a cell supervised by the transceiver station.

Finally, it is clear that numerous variations and modifications may be made to the receiver front-end described and illustrated herein, all falling within the scope of the invention, as defined in the attached claims.